Overview of the last HT-7 experiments

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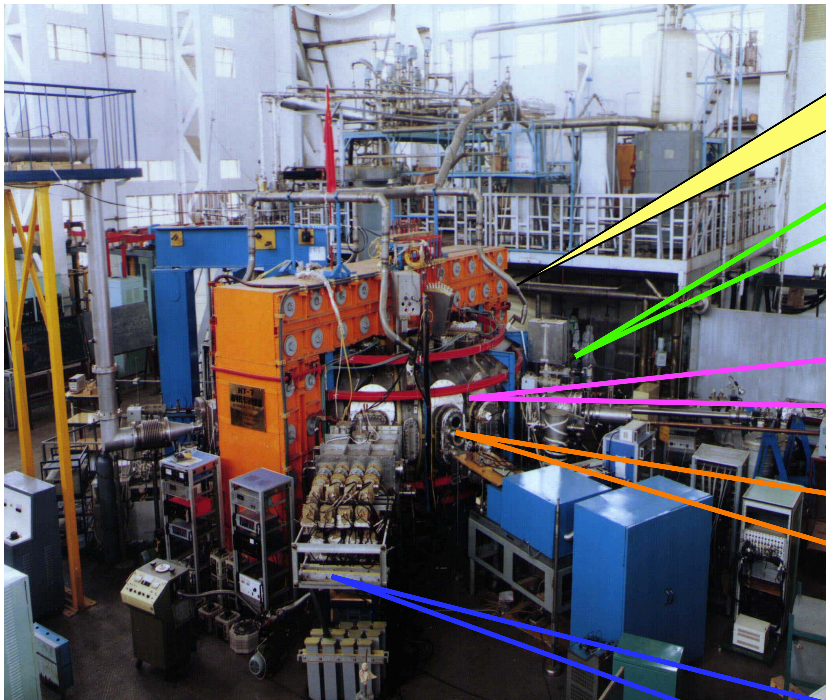
Outline

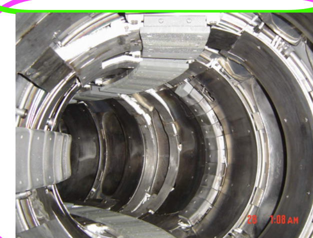
- HT-7 mission and R&D
- Confinement improved scenarios
- High performance under steady state
- Long pulse discharges
- Summary

Main Mission: Steady-state high performance operation and related physics and technologies

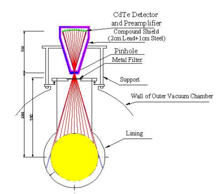


SS real-time PF PS&control

RF: 18-30MHz
350 kW CW
IBW, FW antenna

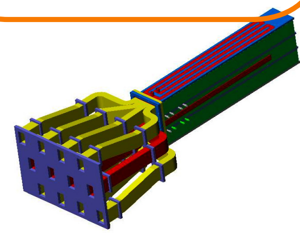


Graphite (P, T)
Water cooled



Schematic diagram of vertical CdTe detector array on HT-7

>30 diagnostics
Steady-state



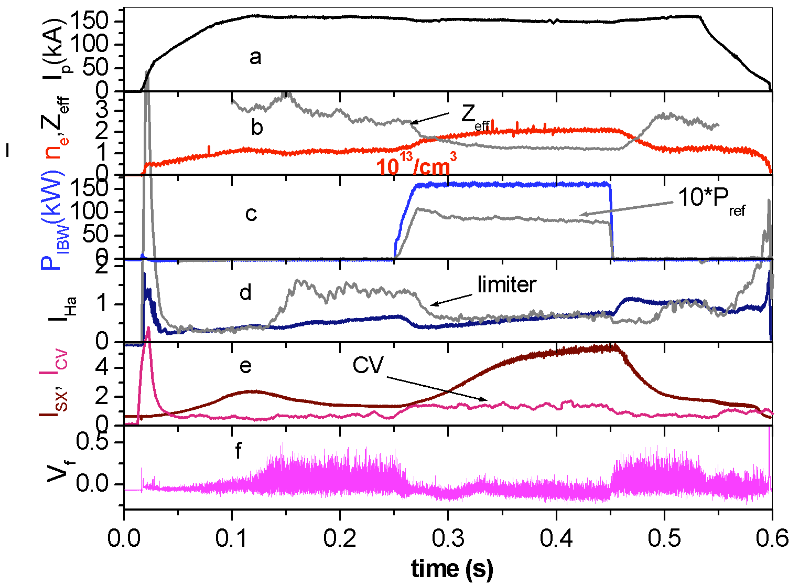
f: 2.45 GHz
1.2 MW CW
Multijunction

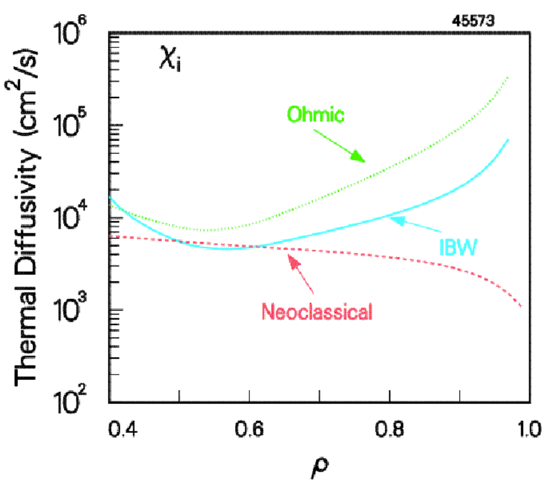
R = 1.22m, a = 0.27m ,

Ip = 100~250 kA, B_T = 1~2.5T

H-mode by IBW at 30 MHz

HT-7

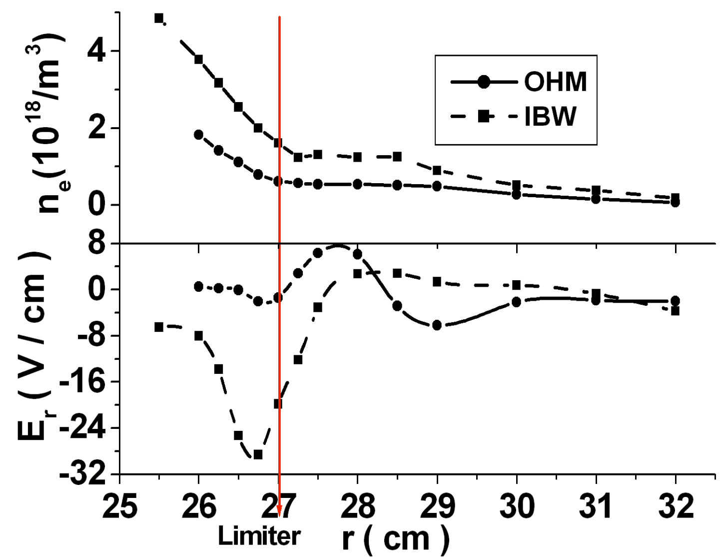




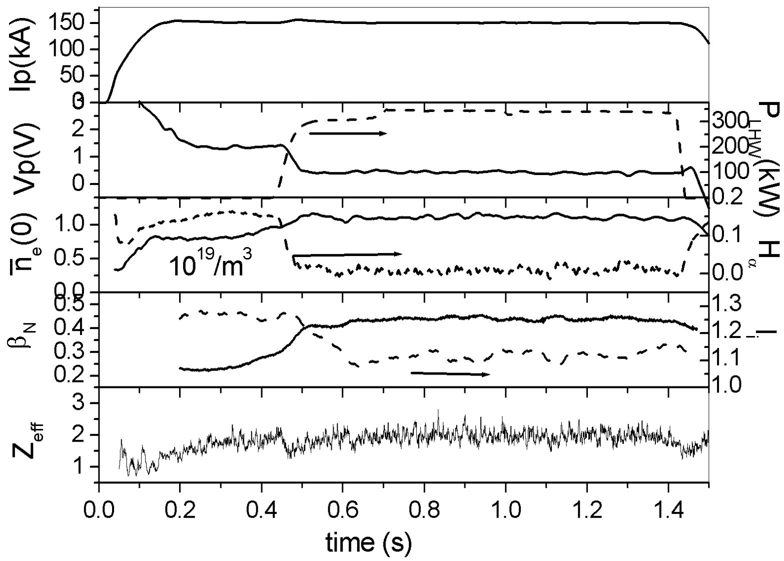
IBW enhanced the edge E_r shear, $\omega_{E\times B} > \Delta\omega_t \sim ck_\theta T_e/eBL_n$ (for drift–wave-like turbulence)

Suppression of edge turbulence leading to improved confinement

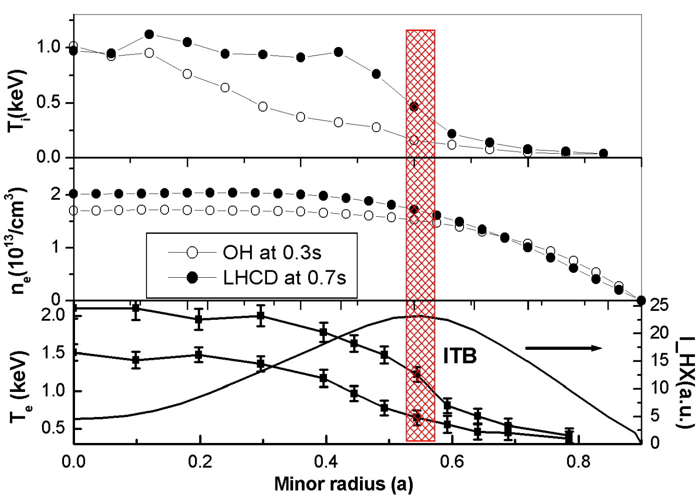
Reduced transport in $\rho > 0.5$

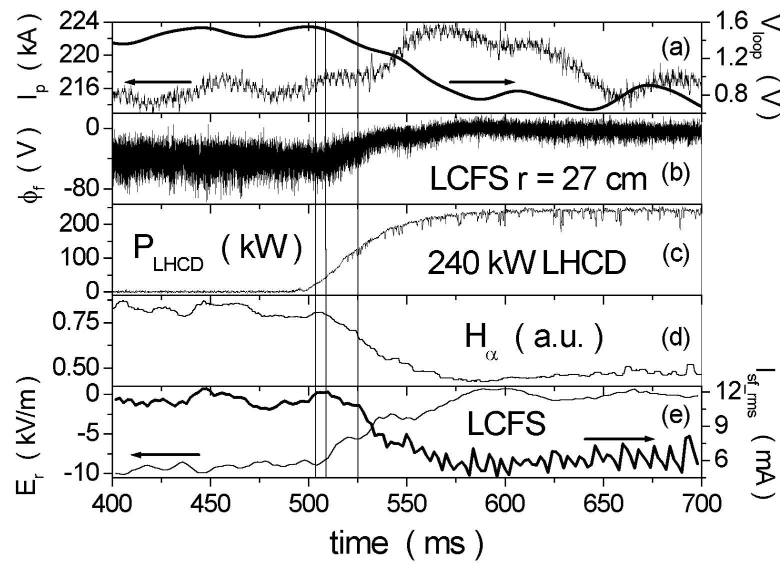


H-mode by off-axis LHCD



- Current density profile control by changing $n_{||}^{LHW}$
- $H_{89} \leq 2$, with potential steady-state capability, but low β
- Enhanced edge E_r shear led to suppression of edge turbulence
- Improved confinement





High li mode

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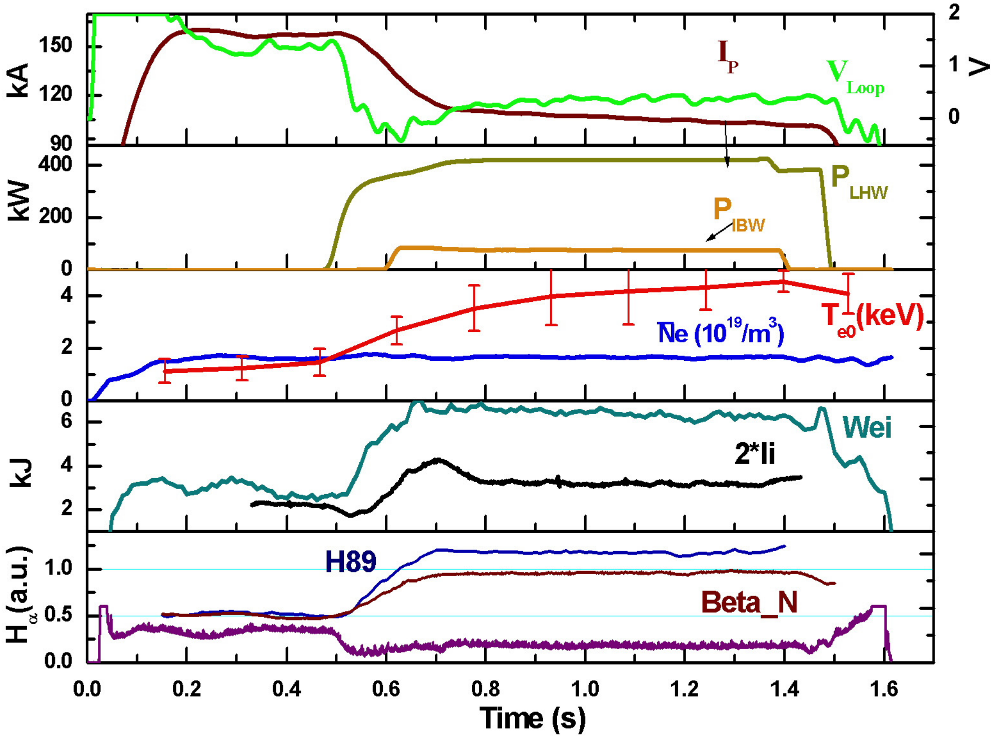
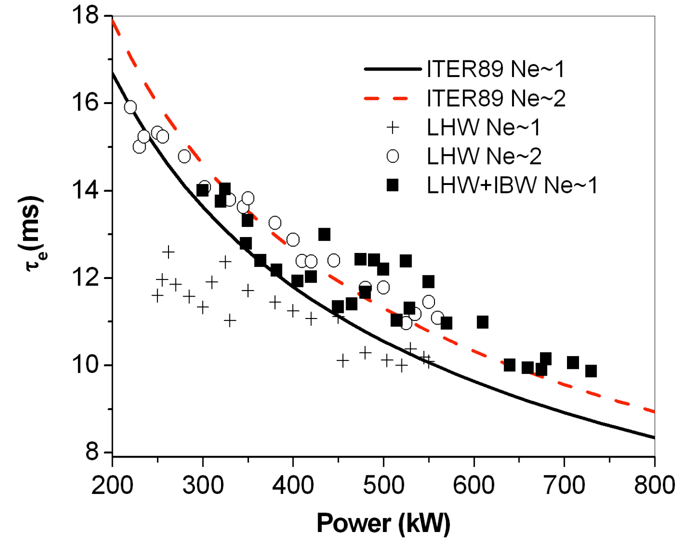
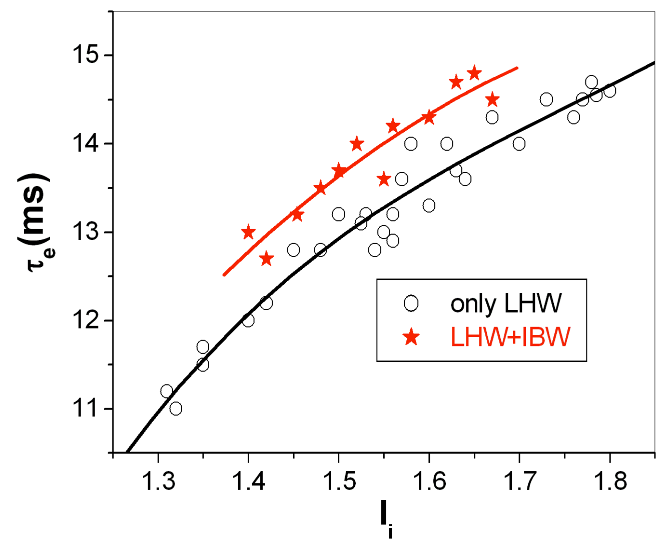
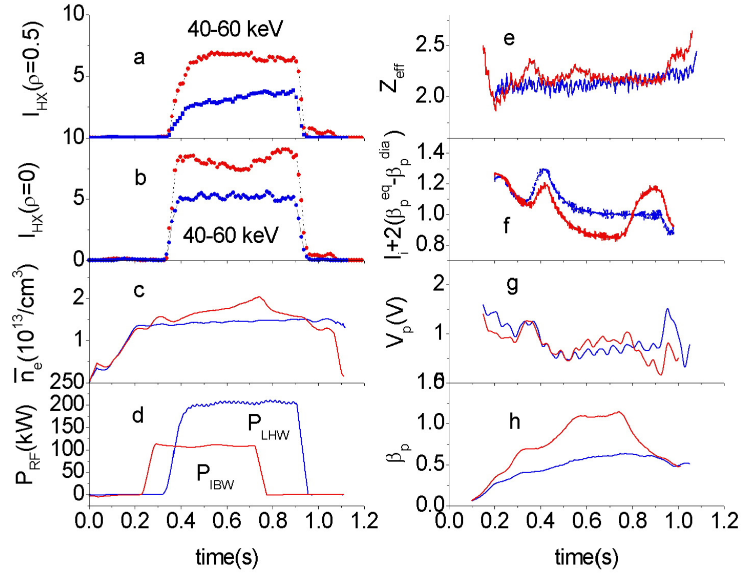




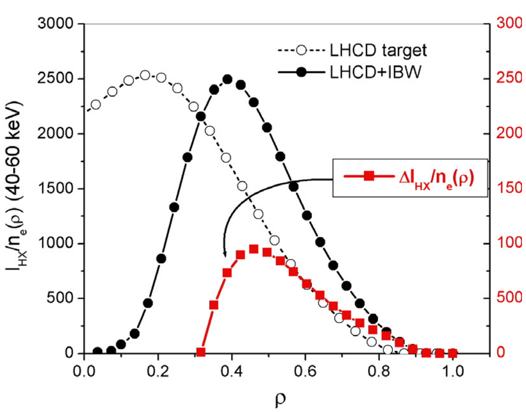


- Ip ramp-down at rate of -0.5~ 1.2MA/s
- Strong peaked Te(r), Te_{max} ~ 4.5keV
- Steady-state high li~1.3-1.8 for several τ_{CR}
- Better confinement with LHW+IBW
- Better confinement for higher li

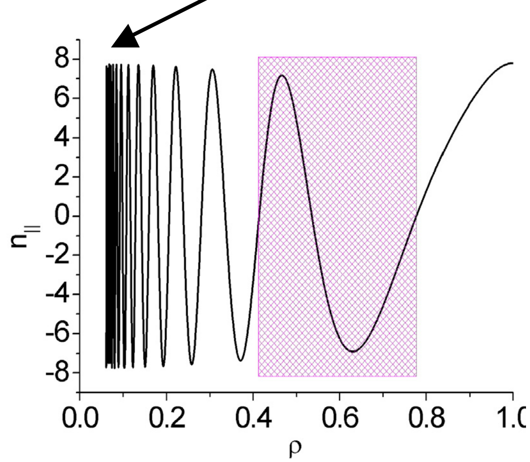
Local synergy of IBW and LHCD



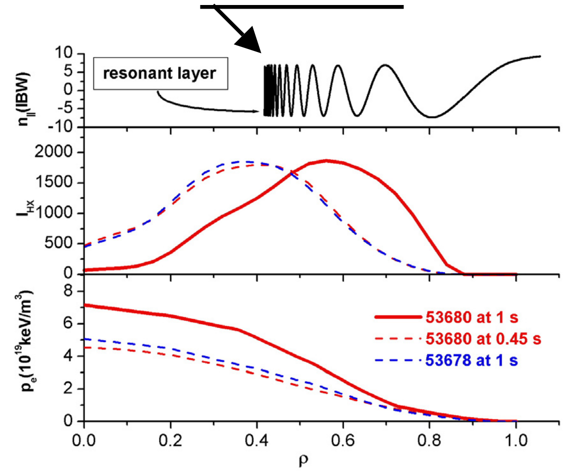
- Ip = 150 kA, $N_{||}$ = 2.35
- LHCD: near on-axis in the target
- IBW **on-axis:** localized HXR at $n_{||\,(max)}$
- IBW **off-axis:** Enhanced HXR at ~Ω_H
- **Broadened current profile**
- **Improved τ_E and τ_p & enhanced β**
- **potential SS capability**



on-axis



off-axis



Features of IBW + LHCD synergy

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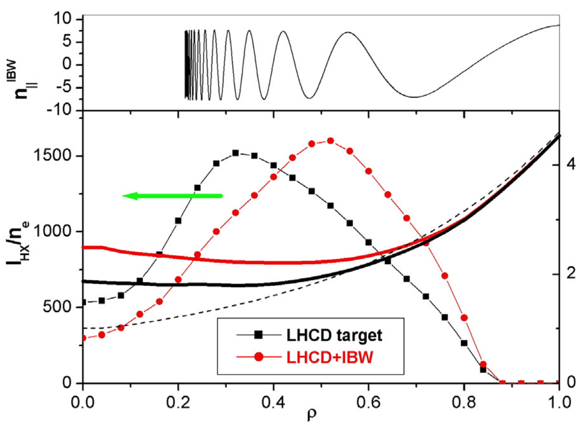
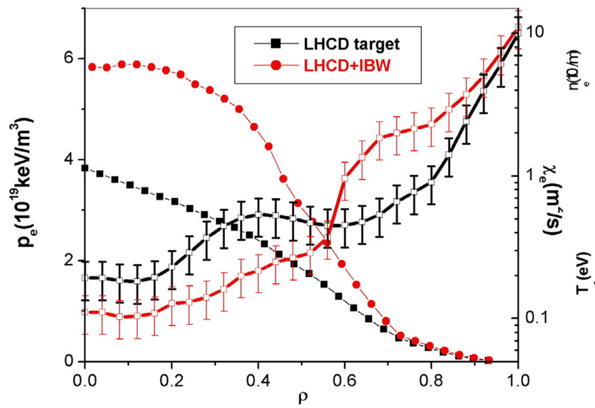
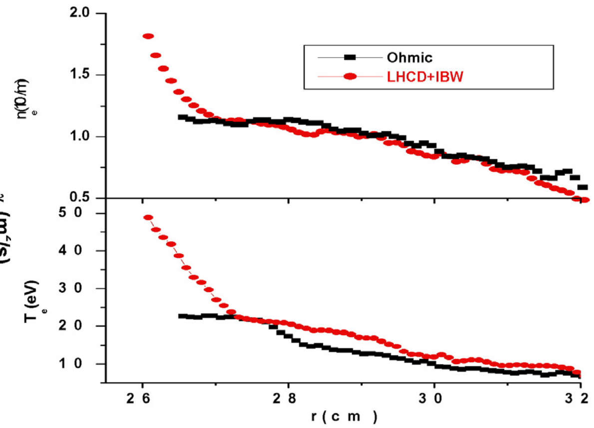
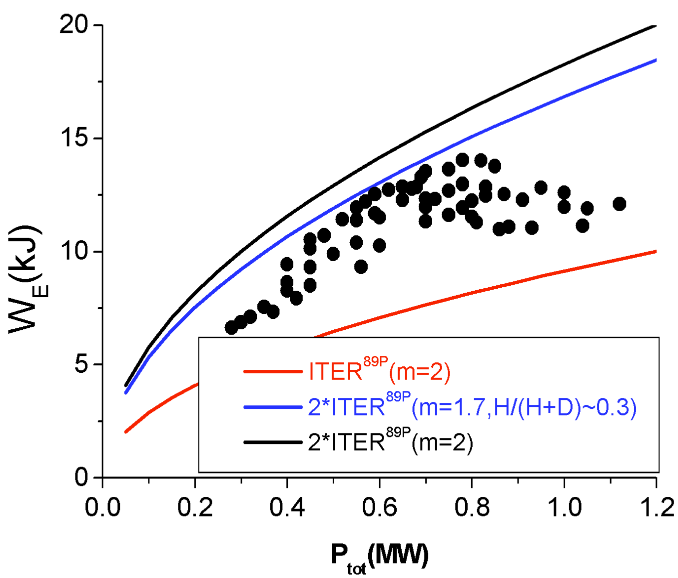
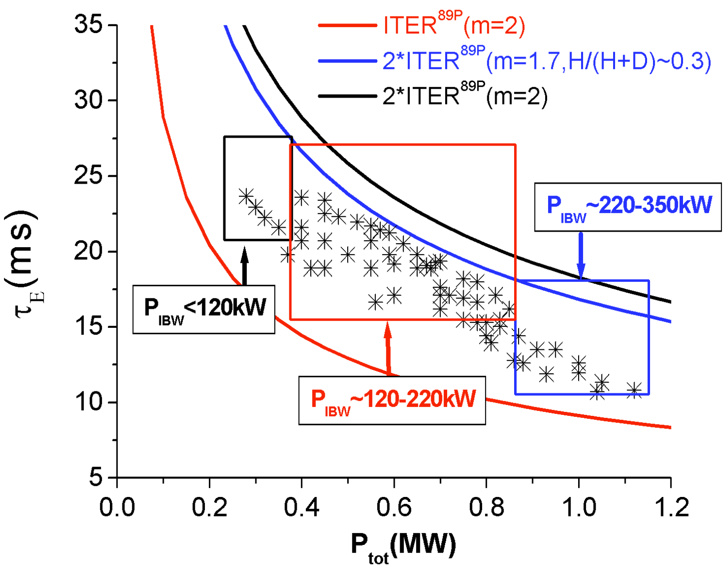






Weak negative shear **ITB at minimal q** **H-mode edge**





Up to 1 MW good confinement

Integration strategy

Interaction of LHW and IBW can help localization of LHCD, create localized current channel and form weak positive or negative sheared q profile and ITB at well defined region by IBW.

To get high performance plasma under steady state condition, strategy was chosen to:

- **Apply RF power at earlier phase of discharges.**
- **Avoid MHD instability via current density profile.**
- **Maximize plasma performance via pressure profile.**
- **Under RF boronized wall condition.**

Compromise was made between performance and sustaining time.

Integrated high performance

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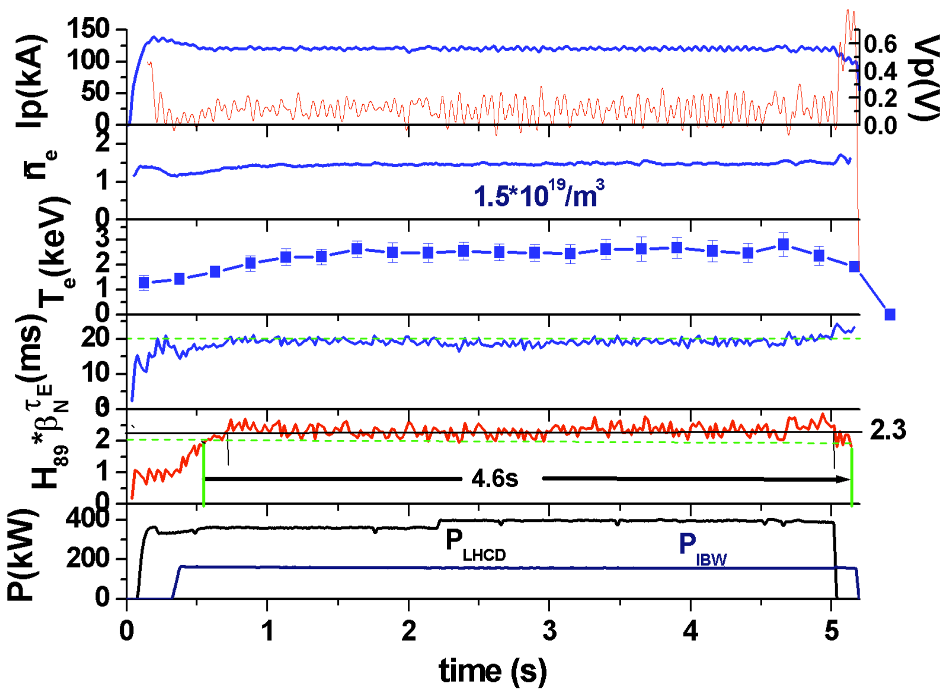
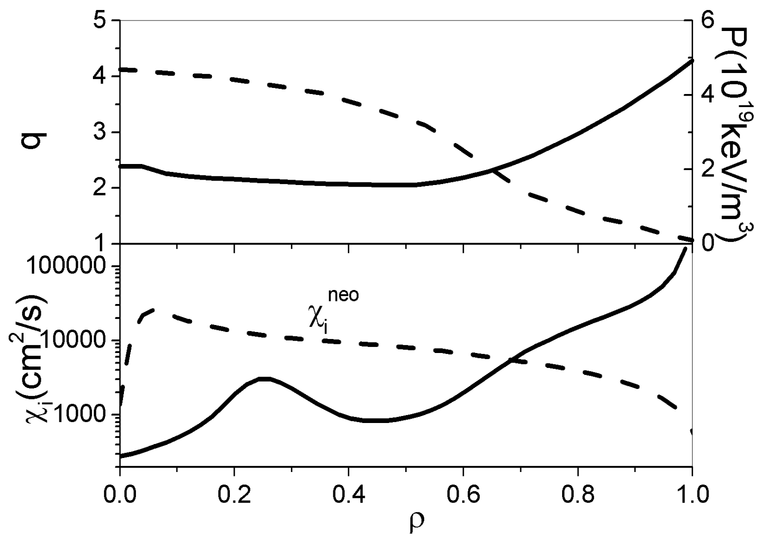
H89*β_N >2.2 for ~220τ_E & > 20 τ_{CR} f_{LHCD}+f_{BS} >80%, Vp<0.10V

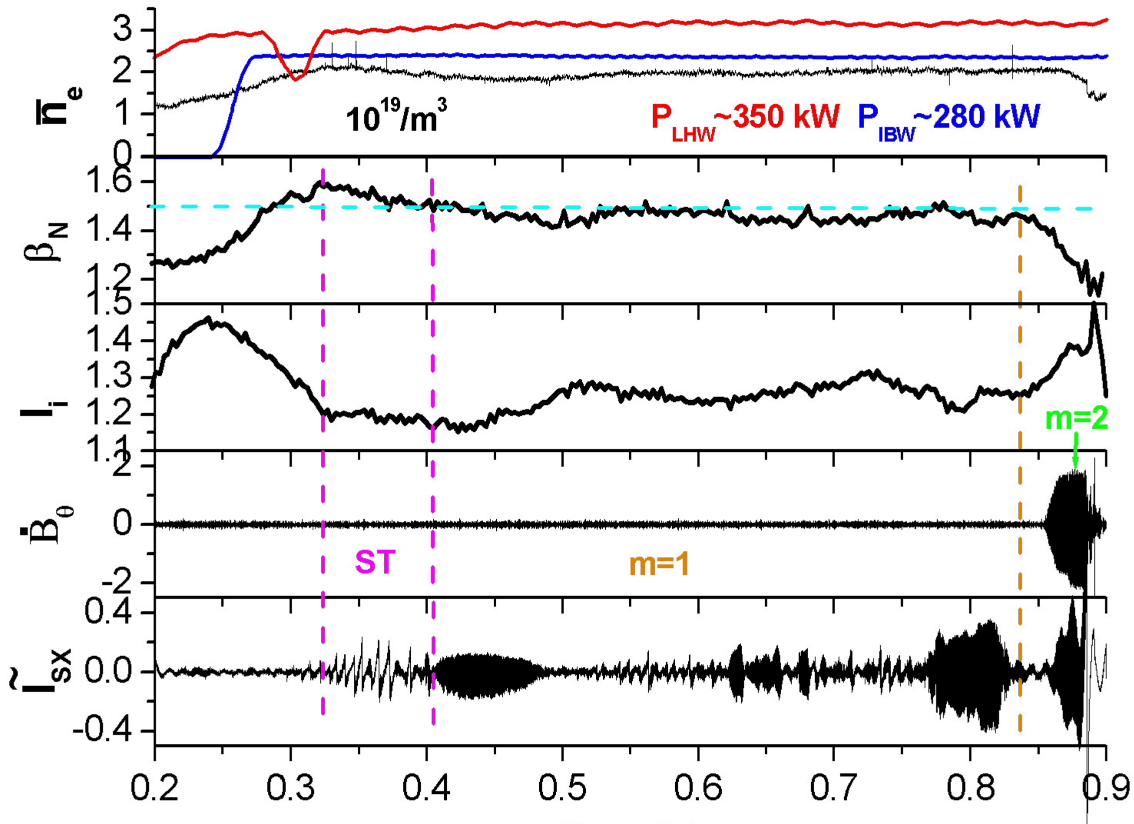




Stationary ITB was formed at footprint of minimal q and sustained during LHCD and IBW. f_{LHCD} ~ 42%, f_{BS}~39%

Limitation of high performance

$H_{89}*\beta_N$ ~2.8 MHD instabilities limit higher β_N



Limitation of high performance

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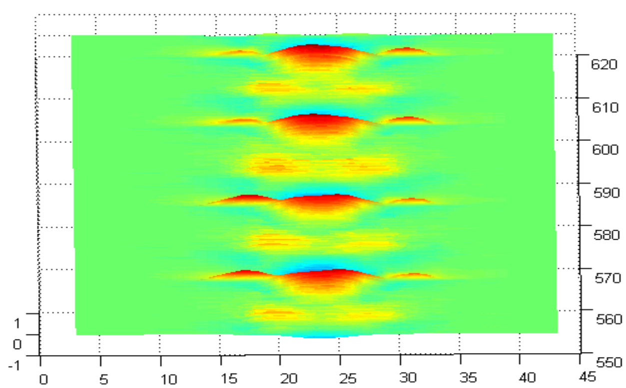
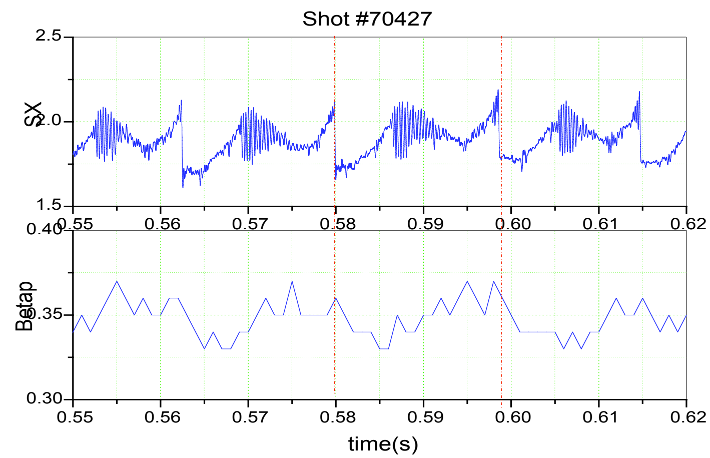
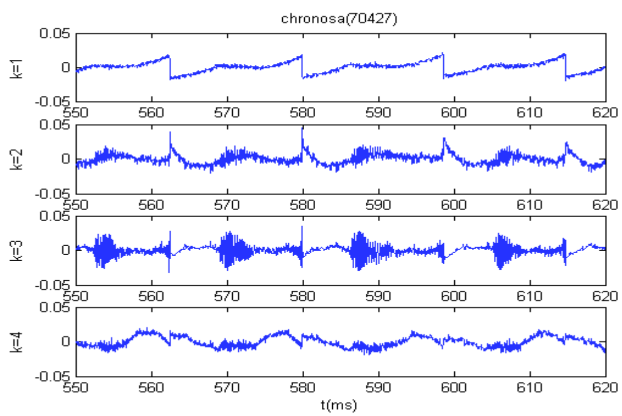
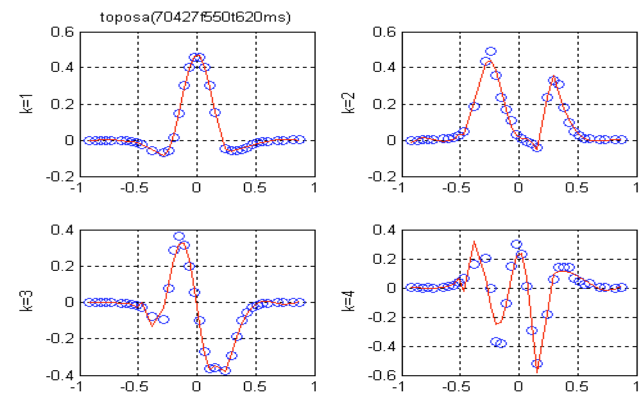
Kinetic effect of fast electron coupled with m=1 internal kink mode?







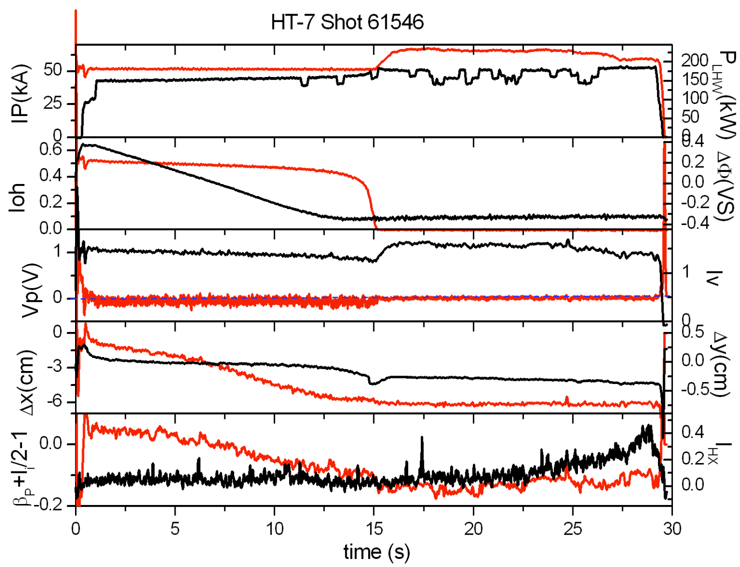


SVD analysis shows: ST, m=1 kink mode with small m=2 tearing

Discharge w/o ohmic current

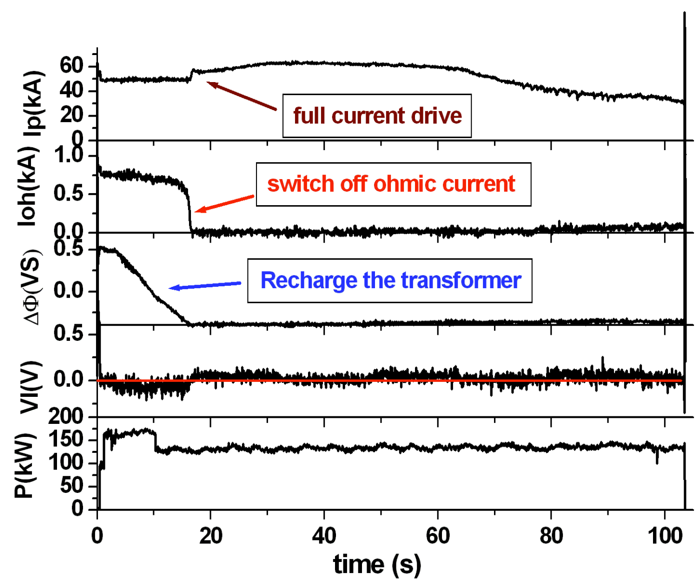
HT-7

Over LHCD recharged the transformer, the current in central solenoid was switched off when the transformer was reverse saturated



In 2003, sustained for 28 s
Density build-up terminated discharge

In 2004, sustained for 80s
Reflection protection terminated discharge



Long pulse discharges in 2004 (mode 2)

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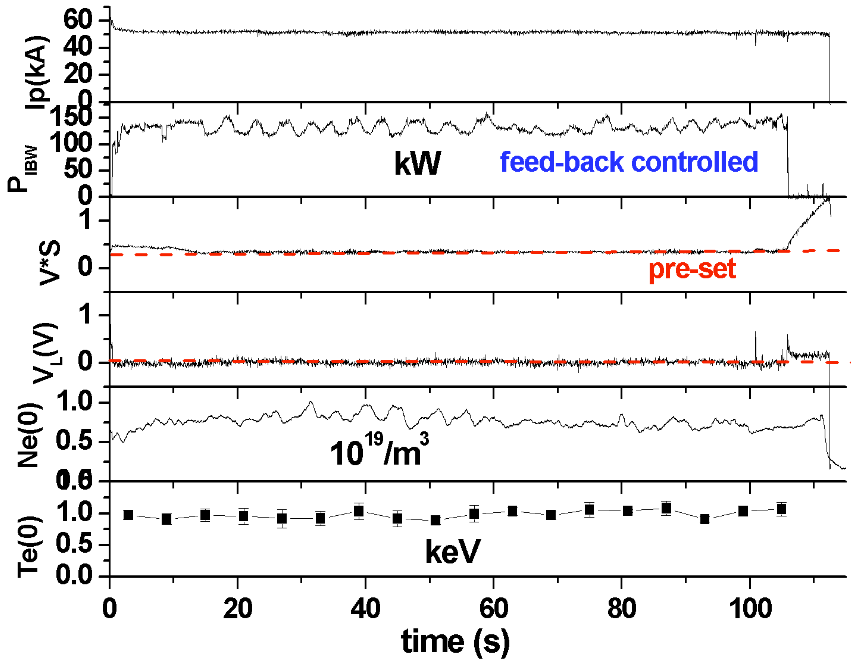
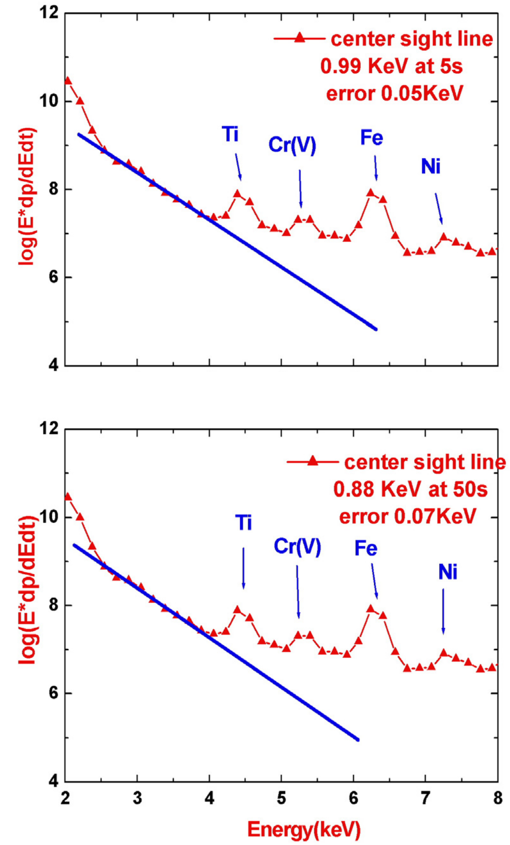


Power feed back control by regulating high voltage power



Metal impurity problem alleviated

Long pulse discharges 4mins in 2004

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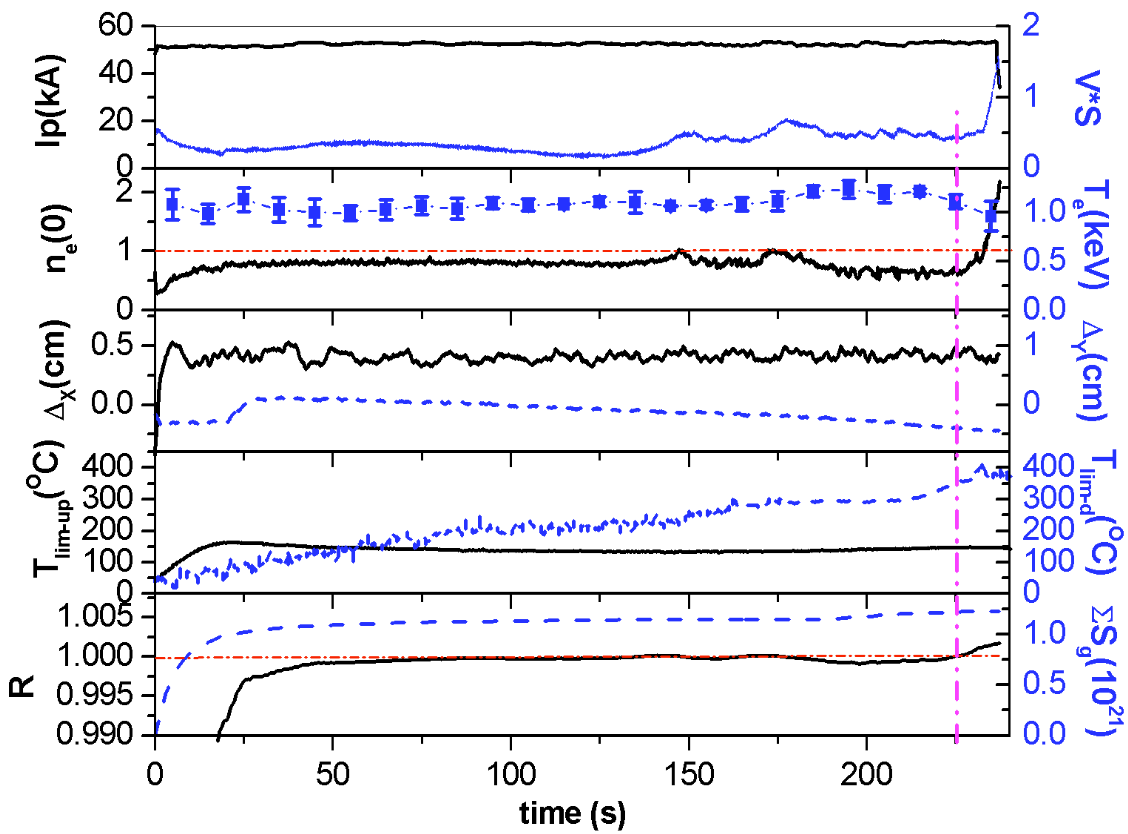
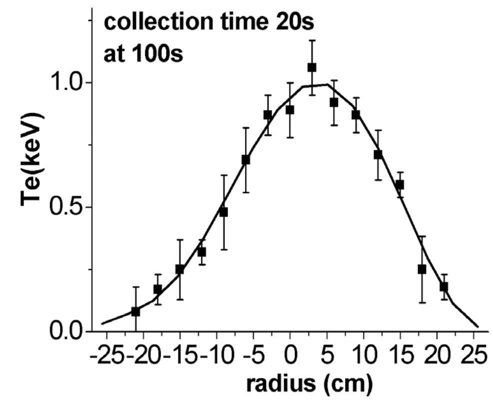


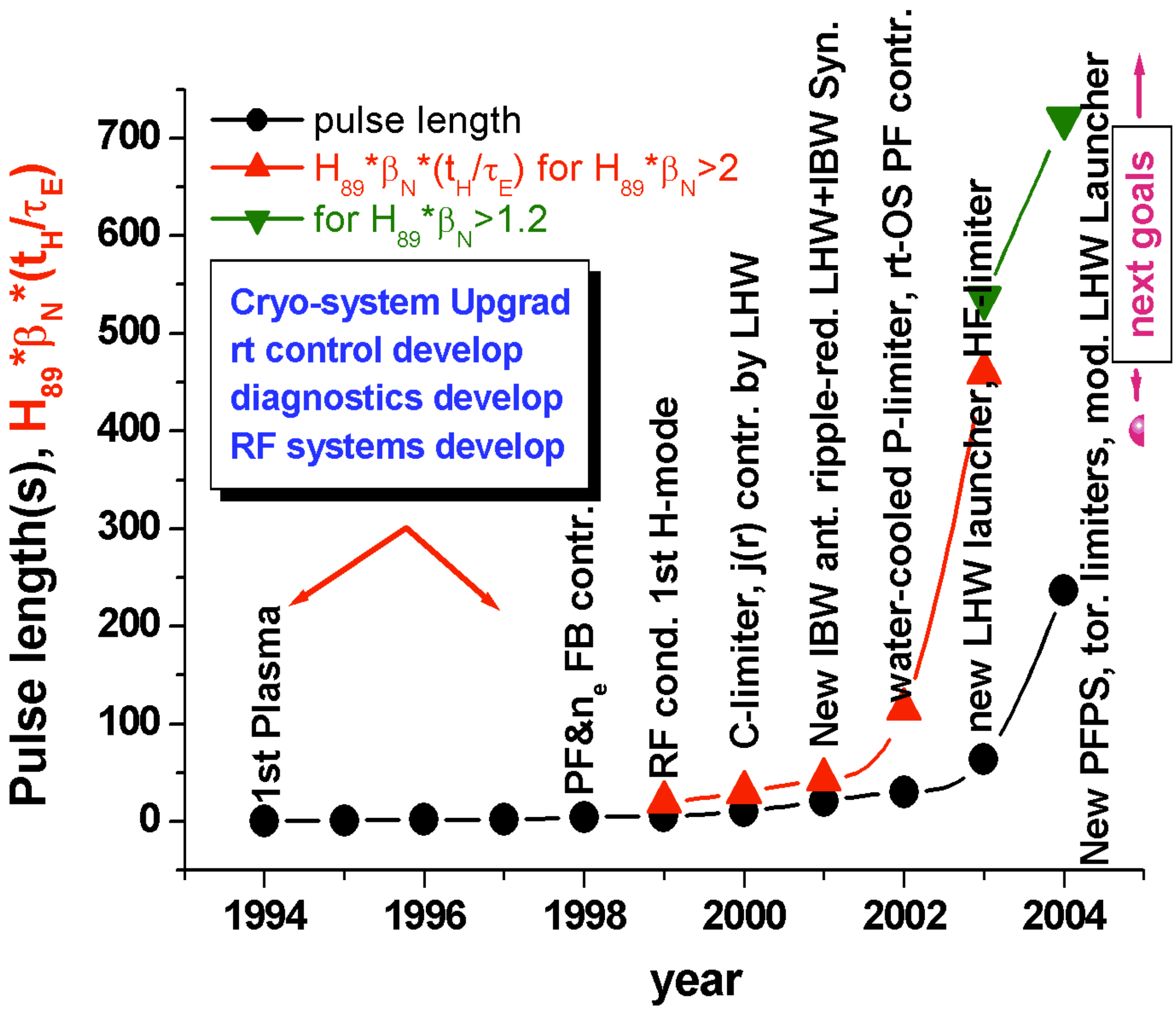


- Ip≥50kA, $n_e(0)$~$0.8\times10^{19}/m^3$, Te(0)~1keV
- Wall saturation at ~80s and refreshed at ~180s
- Limiter temperature rise caused uncontrollable density at 225 s

Power feed back control by switching on/off spare klystrons

Milestones in HT-7

HT-7



Future plan

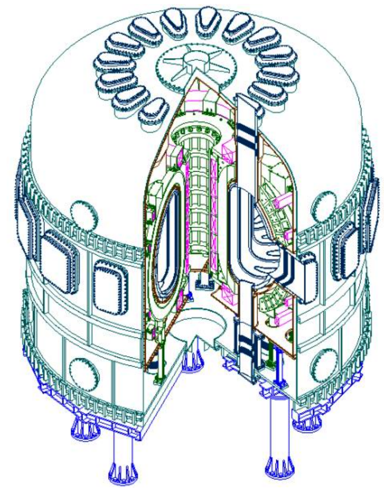
HT-7&EAST

- TF coil cooling at 3.8k, for routinely B_T = 2.5 T .
- New operation regime at I_P=250 kA .
- Total injection power P > 2 MW .

To investigate:

- Plasma and wave interaction.
- Materials for PFC.
- Plasma confinement and transport.
- Simulation of advanced scenario.
- Advanced plasma diagnostics.
- Advanced plasma control.

Oriented to support the EAST project both scientifically and technically.



Major Radius R_o 1.75-1.9 m
Minor Radius a 0.4-0.5 m
Toroidal Field B_o 3.5-4 T
Plasma Current I_P 1-1.5 MA
Elongation K_x 1.6 - 2
Triangularity d_x 0.4-0.8
Pulse length 1000 s
Heating and Driving:
(first phase)
ICRF 3 MW CW
LHCD 3.5 MW CW
ECRH 0.5 MW
Configuration:
Single null divertor
Double-null divertor
near double null

Summary

- HT-7 experiments are strongly oriented to steady-state high performance plasmas and long pulse discharges.
- Technical improvements made great progress in achieving high performance plasmas under steady-state condition.
- Various scenarios of high performance plasma discharges (including edge H-mode, RS mode, high li mode etc) were realized.
- Stationary high performance plasma with $H_{89}*\beta_N > 2$ has been sustained for $> 220\ \tau_E$ and $>20\ \tau_{CR}$.
- Long pulse discharge up to 4mins is successful with the new up-down toroidal belt limiters.
- Further experiments in HT-7 are strongly oriented to support the EAST project both scientifically and technically.